Magmatic Seismo-facies and Crustal architecture along selected profiles in Arabian Sea, West Coast of India

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Extended Abstract

Comprehensive study has been carried out by integrating high resolution seismic, free air gravity and drilled well data to map magmatic seismo-facies across west coast of India and to infer crustal scale processes operating over there. Different episodes of magmatic activities might have modified the crustal scale geological features and influenced tectono sedimentation processes along West Coast Margin of India (WCMI). Various volcanic seismic facies units identified in the studied profiles are Landward Flows, Seaward Dipping Reflections (SDR), Volcanic Protrusions, Domes, Lower crustal reflector (LCR) and Intra basement reflector (IBR). The LCR below basement corresponding to the interface of upper crust and denser lower crust magmatic body has been mapped and it may also represent moho surface or top of under plated magmatic bodies. LCR along these two profiles mimic the free air gravity signatures. Based on prevalence of magmatic characteristics, the probable limit of continental crust domain has been identified. The deformations related to large scale intrusions of Laccadive ridge giving rise to collapsed extensional grabens have been documented. Listric normal faults detaching at LCR level and giving rise rollover structures of layered volcanic have been observed to the east of Laccadive ridge. The massive intrusive body below Laxmi ridge could be observed in the seismic. Low gravity observed over Laxmi ridge may be attributed to downwraping at LCR (?moho), formed due to the load/ overcrusting of excess magmatic materials below Laxmi ridge. The present model and approach will help in assessing exploration risk and reduce risk and uncertainties in exploration programme in deep water areas.

1. INTRODUCTION

Different episodes of magmatic activities have been documented in the Western Continental Margin of India (WCMI) related to India and Madagascar separation during late early Cretaceous period ranging from 83 to 88Ma. The latest dating for the outpouring of the bulk of the Deccan Trap flood basalts in NW India seems to converge around 66-65 Ma. The Tertiary basalts encountered in wells and mapped on seismic data in the Kerela-Koankan area are younger in age (~ 62-58 Ma) and related to Laccadive Ocean Island Basalt. These magmatic events might have modified the crustal scale geological features and

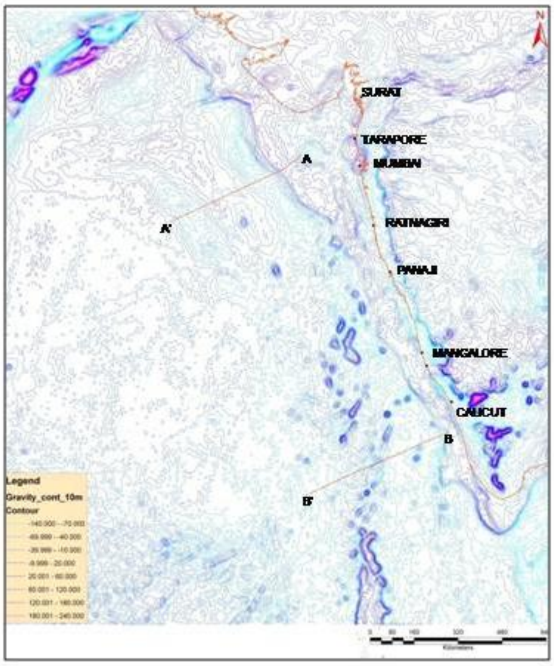

Fig-1: Free air anomaly map showing studied profiles (A-A', B-B')

influenced tectono sedimentation processes along WCMI. In the present study magmatic seismic facies has been identified along two high resolution seismic profiles originating from shelf to ultra deep water, one across Bombay offshore platform – Laxmi ridge (A-A’) and other passing through Kerala offshore through Laccadive ridges (B-B’) (Fig-1). The main objective of this paper is to investigate the variations in volcanic eruption and emplacement processes in WCMI focusing on identification and mapping of volcanic seismic facies units to infer crustal architecture.

2. GEOLOGIC HISTORY

The western continental margin basins owe their existence through fragmentation of Gondwanaland by three stages of rift and subsequent drift mechanism. In the first stage, Eastern Gondwanaland (Madagascar, India-Seychelles, Antarctica and Australia) was separated from Western Gondwanaland (South America and Africa) during Late Triassic/Jurassic (~196-203Ma) which is closely associated with Karoo volcanism in South Africa and the conjugate of which are seen in Antarctica. The second stage represents the separation of Madagascar from Seychelles-India, in Late Cretaceous (~93Ma) and associated with minor volcanism on conjugate margins of south-western India and southeast Madagascar. The third stage marks the final break-up of Seychelles micro-continent from India at around 65 Ma and associated with Deccan volcanism at Cretaceous/ Tertiary Boundary (KTB, ~65 Ma).A series of horsts and grabens resulted in response to rifting along the dominant basement tectonic trends (NNW-SSE, NE-SW and ENE-WSW). The northernmost part of the western continental margin was first to be subjected to continental rifting and crustal subsidence in late Triassic and then process of rifting gradually advanced towards south and by cretaceous time all the rift related horsts and grabens came into existence (Subramaniyam etal. 2006, Subramanya, K. R, 1998).

3. DATABASE

The database of this study includes high-resolution 2D seismic regional lines, free air gravity (FAA) map prepared from data downloaded from internet site and drilled well information.FAA map has been interpreted qualitatively in the present study.

4. OBSERVATIONS AND RESULTS

An attempt has been made to study the nature, geological history and emplacement environment of extrusive volcanic from seismic data. Seismofacies analysis is based on methodology and criteria suggested by Rey etal (2008). Different magmatic seismofacies identified in the study area is summarized in Table-1.

Selected uninterpreted and interpreted seismic profiles along with free air anomaly profile are presented in Figs. 2,3,4,5. The seismic profiles (A-A’) in Fig. 4 show the variation in crustal structure. Crustal domains identified from the integrated interpretation are: 1) continental, 2) transitional crust in Fig.4& 5. The crust and ocean transition (COTC) zone has been marked by intensive magmatic activities. Discrete high gravity anaomalies observed in the FAA map could be corroborated with intrusive features identified along studied seismic profile. Horst and graben feature has been identified in the crustal domain. The deformations related to large scale intrusions of Laccadive ridge have given rise to collapsed extensional grabens. Development of listric normal faults detaching at LCR level and giving rise rollover structures of layered volcanic have been observed to the east of laccadive ridge. Intrusive features could be observed within sedimentary sequence overlying regional Trap surface. The massive intrusive body below Laxmi ridge could be observed in the seismic. The low gravity observed over Laxmi ridge may be attributed to downwarping at LCR (?moho), formed due to the load/ over crusting of excess magmatic materials below Laxmi ridge. Similar interpretation has also been done for similar features elsewhere in world like Voring spur, Norway offshore and other places.

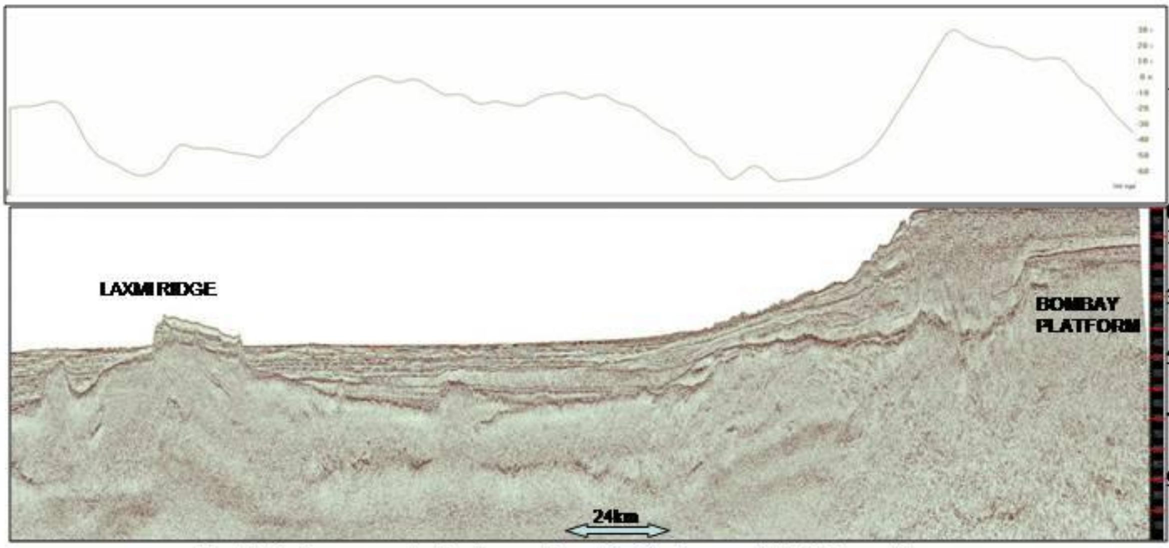

Fig-2: Uninterpreted seismic section (A-A') along with FAA profiles

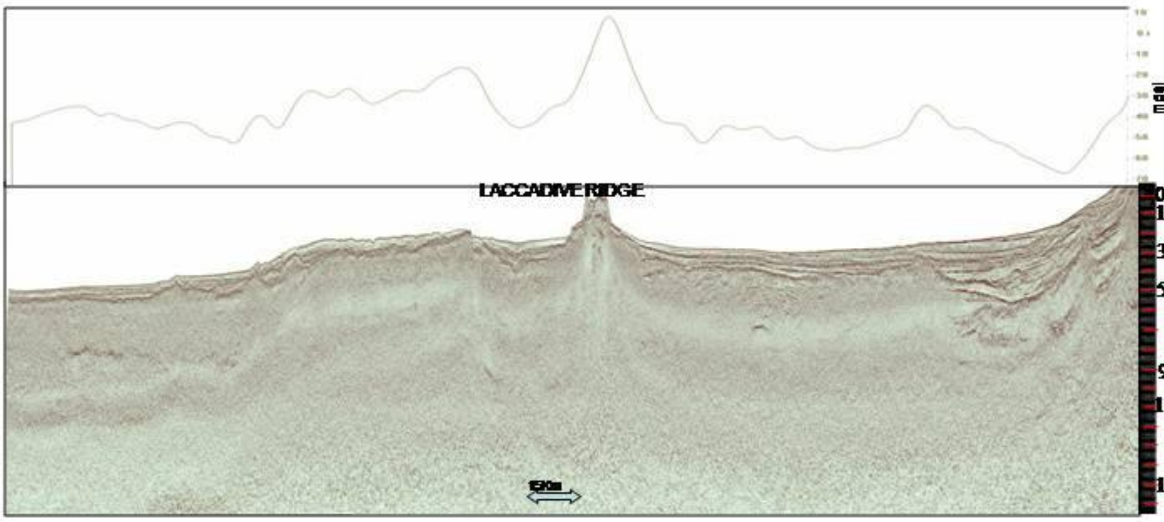

Fig-3: Uninterpreted seismic section (B-B') along with FAA profiles

4.1. **VOLCANIC SEISMIC SEQUENCE ANALYSIS**

The seismic data frequently display characteristic internal reflection patterns overlain by a high-amplitude event. The high-amplitude event overlying the volcanic deposits is interpreted as the upper boundary of the volcanic complex and is named the top of volcanics reflection and is generally easily identified as a continuous, positive, and high-amplitude event.

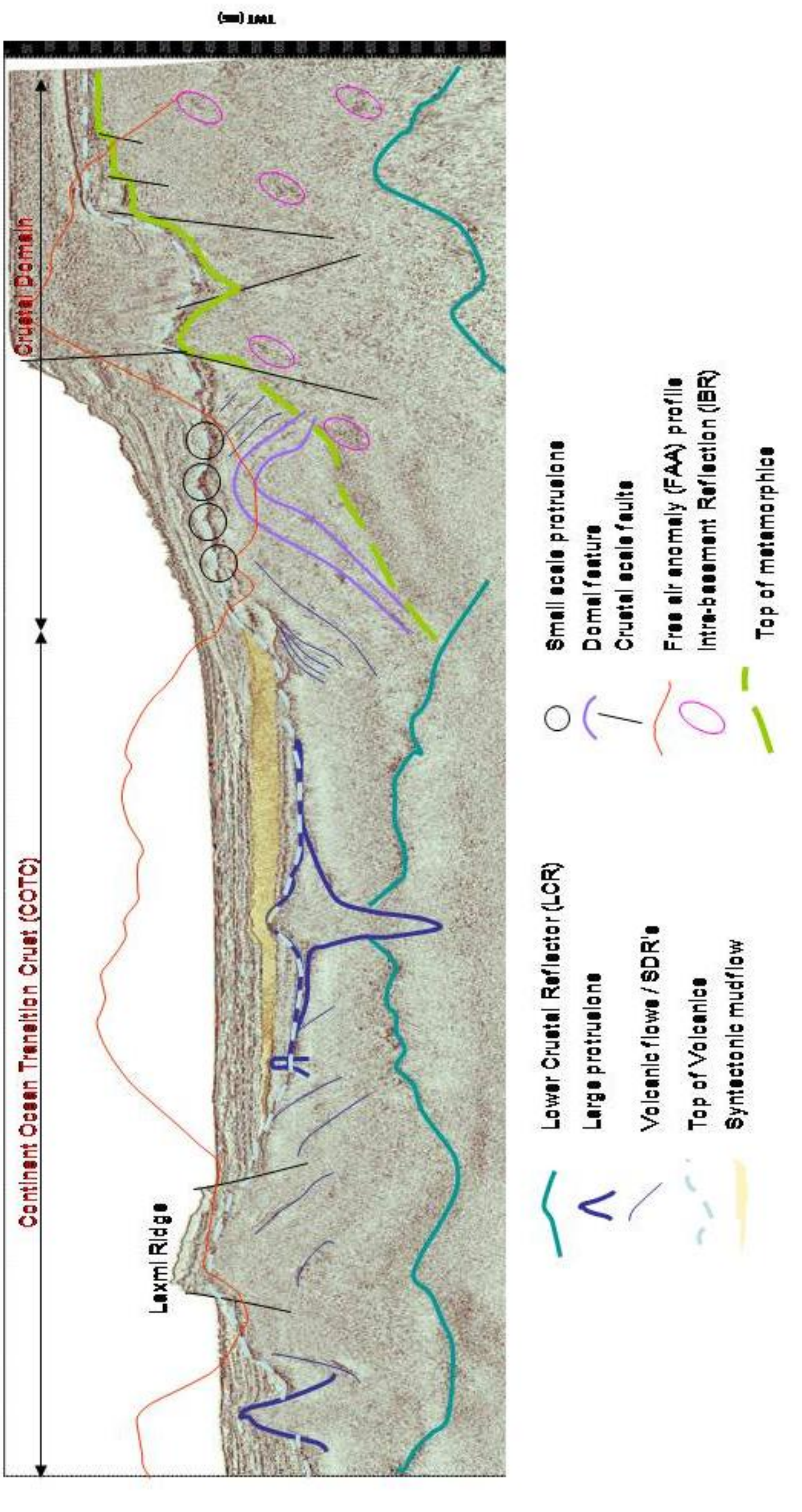

Fig-4: Interpretation of Seismic section along A-A' alongwith FAA showing magmatic facies and crustal architecture

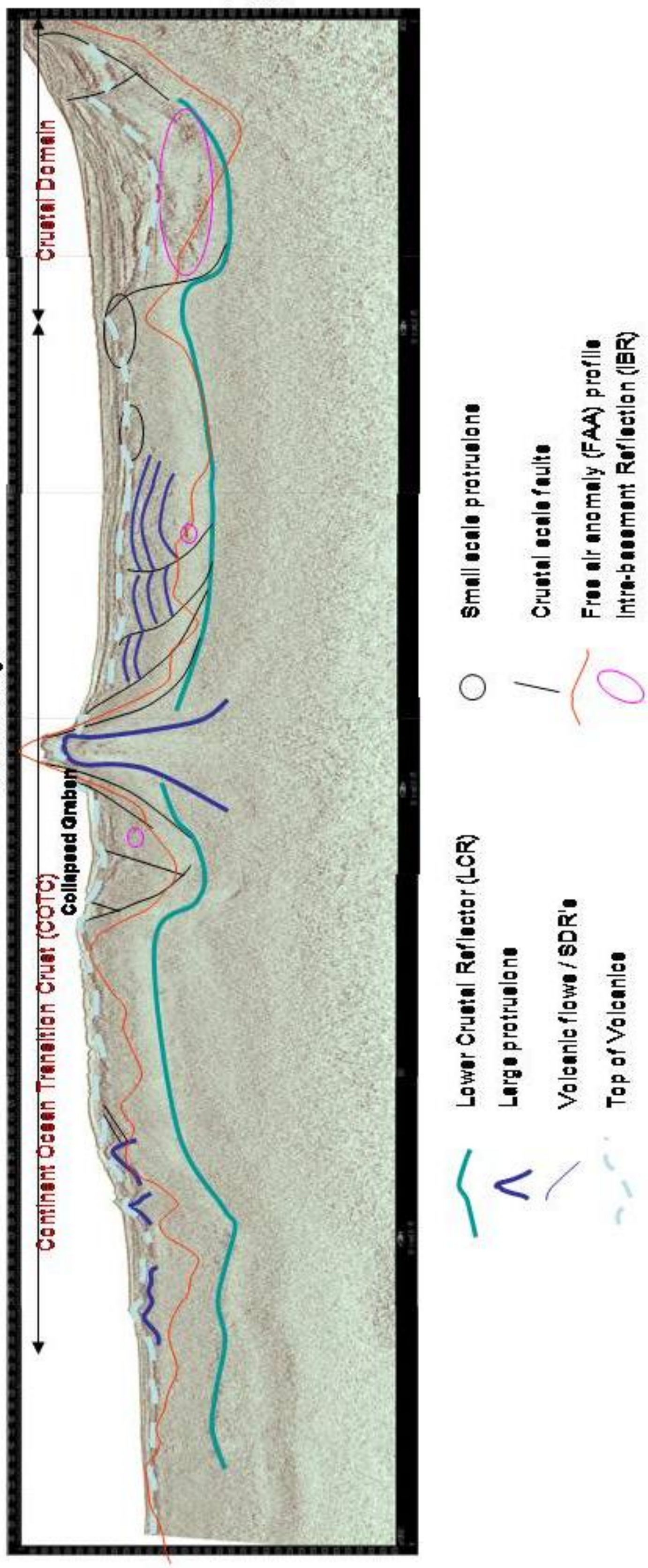

Fig 5: Interpretation of Seismic section along B-B' alongwith FAA showing magmatic facies and crustal architecture

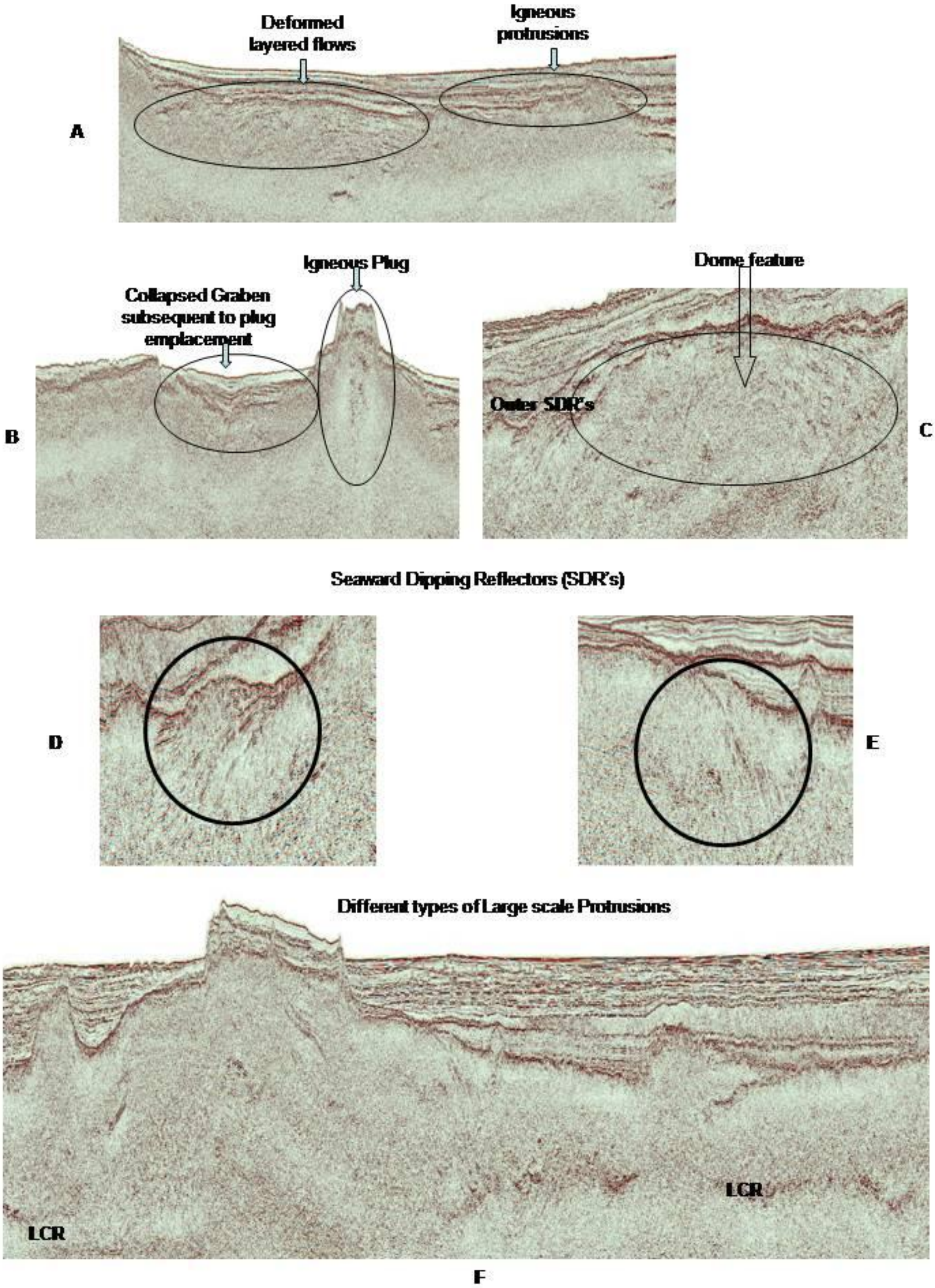

Fig 6: Different seismofacies identified in the studies profiles

4.2. **VOLCANIC SEISMIC FACIES UNITS**

On the basis of the characteristic internal reflection patterns, geometry and shape, volcanic seismic facies units identified described are i) Landward Flows ii) Seaward Dipping Reflections iii) Volcanic Protrusions, iv) Domes, v) Low Crustal Reflector (LCR) and vi) Intra Basement reflector (IBR).

i) Landward Flows are interpreted predominantly on extended continental crust or landward of the Seaward Dipping Reflections on transitional crust.

ii) Seaward Dipping Reflections (SDRs) are prevalent on the transitional crust in the studied profiles (Fig 4, 5, 6D, 6E). The SDR sequences are up to 1.5 s thick and 40 km wide. Most of the SDR, s are located below just top of volcanic.

iii) The Volcanic Protrusions are numerous in the study area and prominent on some of the seismic profiles (Fig 4, 5, 6A). The Volcanic Protrusions are commonly associated with positive anomalies in the free-air gravity. Volcanic Protrusions range in size from minuscule to 2.5 s high and 30 km wide.

iv) The Domes are arched structures that form long ridges or minor rises (Fig 4 & 6C). The relief of the Domes varies from 0.1 to 1 s and they are probably volcanic in nature. Arched internal reflections suggest the domes being associated with deformation structures. The presence of sub-parallel reflections in the Domes located on the transitional crust may indicate post-emplacement deformation of lava flows. The doming and faulting are signs of compressional deformation affecting the Western Margin.

v) Intra Basement reflectors (IBR's) are characterized by high-amplitude reflections of various continuity and with abrupt terminations (Fig 4 & 5). They are often having cross cutting the sedimentary strata.

vi) The lower crustal reflector (LCR) below basement corresponding to the interface of upper crust and more denser lower crust magmatic body has been mapped (Fig 4, 5, 6F). This may also represent moho surface or top of under plated magmatic bodies.LCR along this two profiles mimic the free air gravity signatures. The LCR (Low crust reflector) on the oceanic and transitional crust probably represents the crust–mantle transition. This reflection belt is observed to be continuous and it mimics the gravity profile also.

4.3. SUMMARY OF VOLCANIC FACIES

Table 1: Characteristics of main volcanic seismic facies units observed in the studied sections

Seismic facies unit	**Reflection characteristics**			**Interpretation**
	Shape	**Boundaries**	**Internal**	
SDR	Wedge	Top: high- or intermediate amplitude smooth or with pseudoescarpments. Base: seldom defined.	Divergent-arcute or -planar. Disrupted, "Non-systematic" truncations.	Submarine emplaced flood basalts with thin intrabasalt sediment layers. Deposited in subsiding structural lows.
Landward Flows	Sheet	Top: high-amplitude, smooth to rough, locally faulted. Overlying: onlap or	Parallel to subparallel. High-amplitude, disrupted.	Subaerial or shallow marine flood basalts emplaced on a plain or in a broad basin.

		concordant. Base: low-amplitude, disrupted.		
Volcanic Protrusion	Mound	Top: high-amplitude, smooth or rough. Base: seldom defined.	Chaotic to sub-parallel (short), low to intermediate amplitude.	Submarine emplaced massive basalt (possibly hyaloclastite flows) from fissure eruptions.
Dome	Dome	Top: High to intermediate amplitude. Base: seldom defined.	Parallel to subparallel.	Deformation structure. Formed due to uplift (underplating) or compressional stresses.
Intra Basement Reflector (IBR)	Single reflection	High amplitude, often transgressive and cross cutting strata. Often inhibit imaging of deeper events.		Sills and dykes
LCR	Band	From high-amplitude, single reflection to weak band.	Band of reflections.	Interface of maximum density contrast below upper crust, Crust–mantle boundary (Moho) or top of Underplating magmatic bodies

5. CONCLUSIONS

Different magmatic seismofacies indicating various kinds of intrusions and volcanic flows have been documented along the two selected profiles. Based on prevalence of magmatic characteristics, the probable limit of continental crust domain has been identified. Formation of extensional grabens and other extensional deformation observed close to Laccadive ridge may be attributed to magmatic emplacement mechanism. The low gravity signature over Laxmi ridge could be because of downwarping of at lower crust because of over-crusting resulting from excessive magmatic extrusion. The Lower crust reflector is found to mimic gravity signatures. Hence LCR may be incorporated as constrain for gravity modeling. The present approach will immensely help in assessing exploration risk in deep water areas.

6. REFERENCES

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